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Abstract

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Upper limb-hand 3D display system for biomimetic myoelectric hand simulator

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Abstract— **A graphics system displaying both upper limb posture and opening-closing of a prosthetic hand was developed for real-time operation of our biomimetic myoelectric hand simulator. Posture of the upper limb was determined by 3D position of shoulder, elbow and wrist, which were detected with Optotrack. Finger angle of the hand was given by the simulator, which receive the surface myoelectric signal (EMGs) of both flexor and extensor muscles of the forearm. A non-amputee subject could control smoothly the finger angle by using this display system.**

Keywords— **graphics, biomimetic, electromyogram, prosthesis, simulator.**

I. INTRODUCTION

Many kinds of powered prosthetic hands, controlled by electromyogram (EMG) signals, have been developed [1-7]. Such myoelectric hands are controlled in ON-OFF mode or in simple proportional mode, according to the amplitude of EMG signals. Although much progress has been made, motor functions of such myoelectric hands are still not comparable with those of a natural hand, partly because they are designed with little consideration of the natural control mechanisms in the human hand. If a prosthetic hand has the same mechanisms and mechanical properties as the neuromuscular control system of the human hand, an amputee may be able to utilize almost the same subconscious control that he used before the amputation of the hand when controlling the prosthetic hand.

Therefore, we have been developing a new type of biomimetic myoelectric prosthetic hand that simulates fundamental dynamic properties of the neuromuscular control system of the human hand [8][9]. In particular, this prosthetic hand mimics the properties of both muscle viscoelasticity and gain of the stretch reflex which both varying linearly with muscle activity. The dynamics of the neuromuscular control system was derived by analyzing and investigating tension responses of finger muscle to stretch. While the real dynamics are quite complex, because of the non-linearities and time delay of stretch reflex, we used a simple model representing the dynamics as a first approximation. The amputee could control easily finger angle and compliance of the prosthetic hand in the laboratory experiments.

However, we chose one set of fixed parameters and had not investigated utility of the hand by varying the hand dynamics largely.

Due to the complexity of the actual prosthetic hands, any little change in its design dynamics need a much work in both hardware and software. A simulator is very useful for such a case.

The purpose of this study is to develop upper limb-hand display system for biomimetic myoelectric hand simulator. The simulator allows amputees to try to use the myoelectric hands virtually. This system consists of a measuring system and a display system. In this system, posture of the upper limb is determined by 3D position of shoulder, elbow and wrist, which are detected with Optotrack. Finger angle of the hand was given by the simulator, which receive the surface EMGs of both flexor and extensor muscles of the forearm. The upper limb and hand are displayed with 3D-CG. Myoelectric control experiments are conducted with a non-amputee subject.
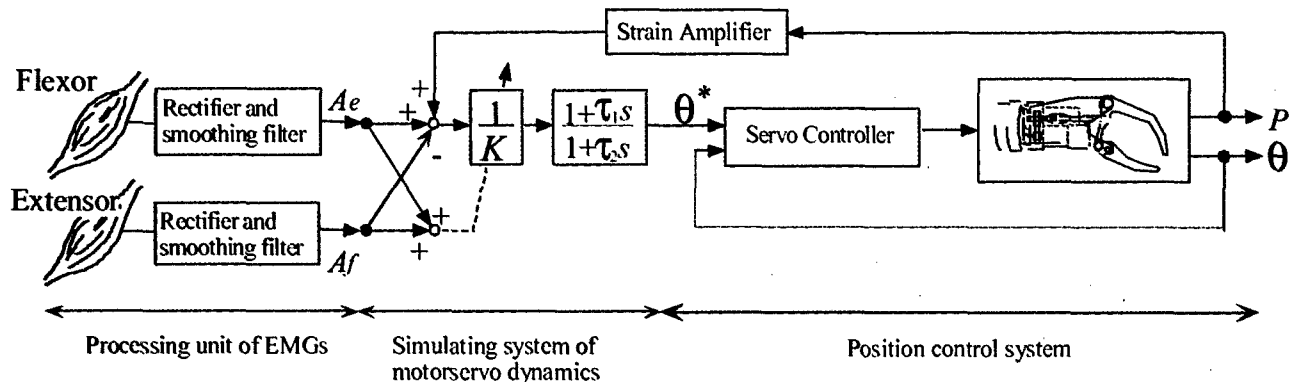
[Fig.-1] Block Diagram of the biomimetic hand

II. SIMULATOR OF THE BIOMIMETIC HAND

A. Design principles of the prosthetic hand model

The main features of this biomimetic hand are the faculty to control by the EMGs of the flexor and extensor muscles the angle of the fingers and the compliance force. In order to obtain such a control, we use a system with the blocks diagram showed in [Fig.-1].

Processing unit of EMGs: a pair of surface electrodes is put on the wrist flexor muscle, and another one on the extensor. The measured signal is full wave rectified and then smoothed with a low-pass filter (cut-off frequency, 2.6 Hz), this low-pass filtered signal corresponds to the contractile force (torque) of the muscle; A_f is for the extensor and A_e is for the extensor.

Simulating system of motorservo dynamics: an estimation of the angle of the final effector, Θ^*, is calculated with (1). Torque, P, is measured by strain gauges attached to each finger.
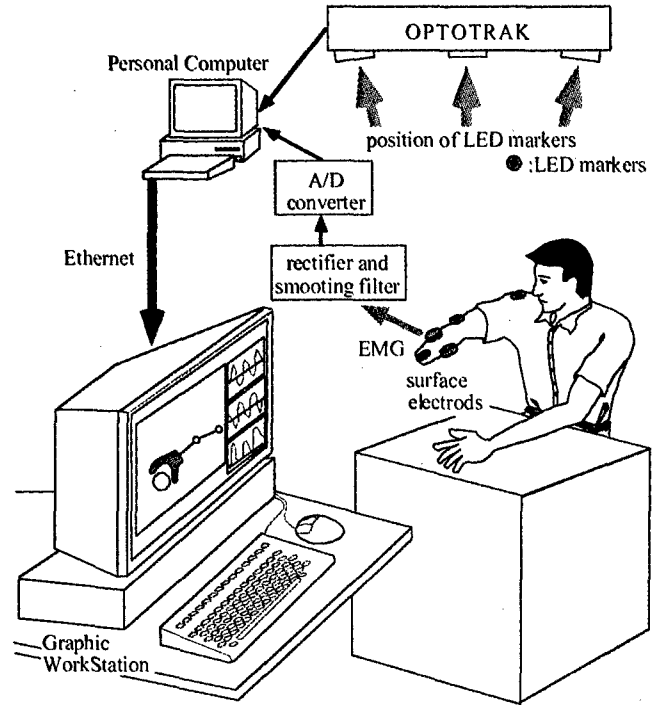
$$\Theta^*(s) = \{P(s) - A_f(s) + A_e(s)\}/G_x(s) \qquad (1)$$

$$G_x(s) = K\frac{1+\tau_1 s}{1+\tau_2 s} \qquad (2)$$

$$K = K_0 + a(A_f + A_e)$$

$G_x(s)$ is the transfer function representing the dynamics of human neuromuscular control system.

The position control system is formed by an end effector that has the ring finger and forefinger linked and they have a one-degree-of-freedom open-close movement respect to the thumb.


[Fig.-2] Simulator sytem

B. Construction of the simulator

Figure [Fig.-2] shows the schematic drawing of the simulator system and [Fig.-3] is the block diagram showing the path of the information.

In the system, the posture of the arm is detected by Optotrack, and the IEMGs of the muscles are captured using surface electrodes and then rectified and smoothed. After that, they are sampled (frequency of 100 [Hz], with a resolution of 12 bit per sample) before be sent to a Personal Computer (DELL,
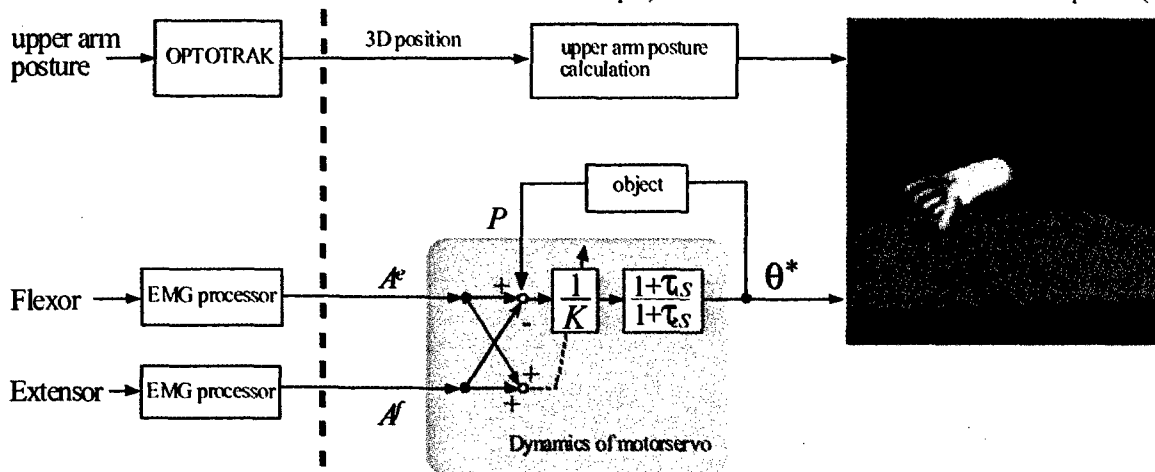
[Fig.-3] Simulator block diagram

OptiPlex).

The upper limb posture is detected by a three-dimensional position measurement device (OPTOTRACK, Nothern Digital Inc.) that detects the position of the LEDs attached around user's shoulder, elbow and wrist. The one on the shoulder is put where the movement of the acromion of the scapula is smallest during the motion of the arm. The one on the elbow is fixed in the external palate of the humeral. In order to obtain the position of the wrist even during the external pronation of the arm, 8 LEDs were placed in the external side of a ring-forming tool tighten to the wrist.

The data processed by the DELL Personal Computer are sent via Ethernet, using the TCP/IP protocol, to the graphics workstation (Indigo2 Maximum Impact, SGI).

III. MYOELECTRIC CONTROL EXPERIMENTS

Performance of the simulator was tested by performing the following experiment with a healthy person (male, 24 years old): the 3D location of the arm and the IEMGs were measured while the subject moved the simulated prosthetic fingers. These IEMGs were also used to move the actual biomimetic hand. By this way, we could compare the performance of the simulator with the real prosthesis. The results are shown in [Fig.-4]. The graphic [Fig.-4(a)] is the opening and closing angle of the simulated (dashed line) and the actual (solid line) prosthetic hand. [Fig.-4(b) and (c)] are respectively the estimated torque contraction (IEMGs) of the flexor (A_f) and the extensor (A_e).

It is clearly seen that the closing angle of the artificial hand and its simulation are nearly coincident. In addition, the simulation of the arm posture was also tested by this experiment. It was proofed that both features were achieved in real time.

IV. DISCUSSIONS

Few previous wors have been done about prosthesis simulator. Abul-Haj et al. [10], developed an emulator system for the design of elbow-prosthesis. Myotrainer (Ottobock Inc.) is used for analysis of the muscle signals amplified by the electrodes and patient training reproducible.

In this research, the simulator system makes use of an advanced graphic workstation and of sophisticated three-dimensional position measurement equipment. But in the future development of an inexpensive myoelectrical hand simulator, it is necessary to reduce its cost in order to make it practically exploitable. By the fact that the specialized rehabilitation health centres are connected to Internet, and by working together the user and the medical authorized personnel, it is possible to expect a high level communication and advise exploitation of the simulator in the near future.

Because the simulator developed in this research includes the dynamics of the prosthetic arm and it displays the opening angle of the fingers in a 3D-CG system, the user is able to experience the usefulness of the artificial hand in a very intuitive way without having to use the real one.

solid line: finger angle of the prosthetic hand
broken line: finger angle of the simulator
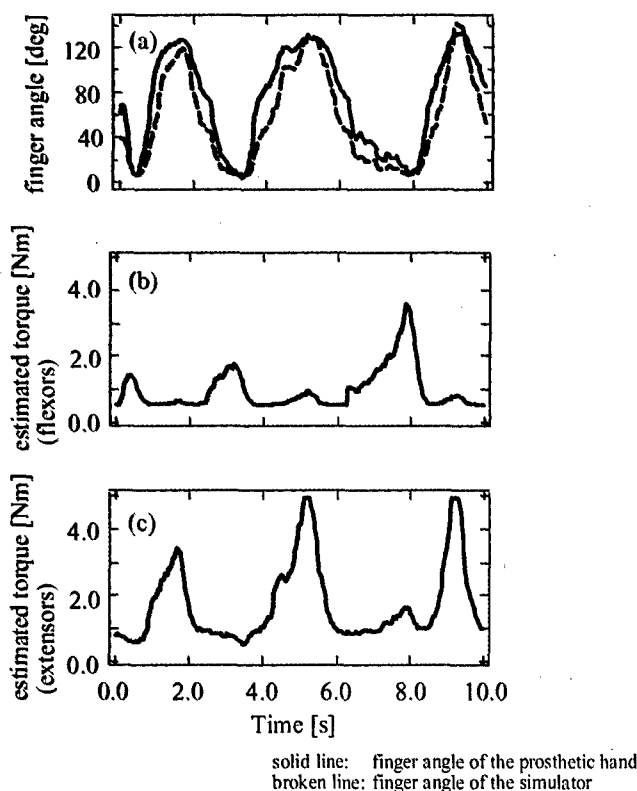
[Fig.-4] Comparison between the simulated prosthesis finger angle and the one in the actual end effector

In order to show the usefulness of the real prosthesis, it is necessary to include in the model actions like grasping objects. For that, it is needed to model the behaviour of the prosthetic fingers opening angle when they support a load. In addition, it is desirable to describe the characteristic of the object to be grasped. In the first step of the development of this biomimetic, myoelectrical, prosthetic hand model, only the simplification of the neuromotor control system has been formulated. But the real end device of the prosthetic hand includes components such as motor, gear and link system, etc, that have non-linear components. The future simulator should also model the dynamics of the position control system.

While this kind of powered prosthesis are quite common in other countries, in Japan it is difficult to find such an artificial hands (e.g., only 350 units have been sold in the last 30 years). With this simulator, we allow disable people to, firstly, examine whether they find a certain design suitable for them or not, testing its usefulness and limitations; and, secondly, they could train with this simulator before start using the real prosthesis, shortening the adaptation required period. In addition, medical doctors and related staff could learn more about this so rare in Japan resource, making in this way possible the general diffusion of its advantages.

V. Conclusion

In this research, we developed the graphics system displaying both upper limb posture and opening-closing of the prosthetic hand for real-time operation of our biomimetic myoelectric hand simulator. Posture of the upper limb was determined by 3D position of shoulder, elbow and wrist, which were detected with Optotrack. Finger angle of the hand was given by the simulator, which receive the surface myoelectric signal (EMGs) of both flexor and extensor muscles of the forearm. A healthy subject could control smoothly the finger angle by using this display system.

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